

# Assesment of hemodynamics by basic ultrasound

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## ABSTRACT

Basic ultrasound can provide important information about the main parts of the circulatory system, the heart, and the main vessels. At the bedside, only by brief visual impression of the heart function and inferior vena cava diameter, and without any measurements, the attending physician can get important information which can influence the clinical opinion-making process and the management of the hemodynamically unstable patient. No less important is to obtain information about the lungs, particularly to estimate if extravascular lung water is present in excess or not. Ultrasound can help in the detection of the potentially reversible causes of hemodynamic instability or arrest and can guide the treatment. Examples are pneumothorax, cardiac tamponade, thromboembolism, the detection of blood in the pleural, pericardial or abdominal space after trauma and the detection and treatment of the source of the infection.

*Key words: ultrasound, hemodynamic monitoring, shock*

## INTRODUCTION

Ultrasound is valuable in recognizing and understanding clinical problems. Bedside available, lacking side effects, not time consuming, and of relatively low cost compared to other imaging modalities, it became a useful addition to classical physical examination. It is particularly attractive in the intensive care unit (ICU) setting, where the transportation of patients out of the ICU is unpractical and potentially risky (1-4). The data obtained by a bedside ultrasound examination performed by an attending physician can immediately, and without any delay, be incorporated into the

clinical decision-making process. The exams can be repeated, so that the ultrasound also becomes a monitoring tool.

In the ICU, bedside ultrasound is a standard of care today. It provides insight into the most important elements of the circulatory system so that much useful information about a patient's hemodynamic can be obtained. The level of expertise can differ, but even with a basic ultrasound education and acquisition of rather simple skills with short learning time curve, useful information about a patient's pathophysiology becomes available after only a brief orientation at the bedside through the use of the ultrasound. The main elements of the circulatory system are: heart as a pump, circulatory volume, and peripheral vascular resistance. Basic ultrasound provides direct insight into the heart function and filling status, while the status of the third variable, peripheral vascular resistance, can be concluded indirectly. Short visual impression of the heart morphology and function, and the filling status of inferior vena cava quickly achieved through the use of the ultrasound provide essential data for understanding the actual problems in a patient's haemodynamics. These data can be immediately included in the process of clinical thinking and decision making. Other indirect signs, which are eventually the causes or the consequences of the impaired haemodynamics such as lung edema, free fluid in the body cavities, and the other findings, can be detected by ultrasound and included into a clinician's understanding of the patient's pathophysiological processes.

## FOCUSED CARDIAC ULTRASOUND

Comprehensive echocardiography is a method by which precise insight into heart morphology and function can be achieved.

This is an exact and reproducible method, but it requires a significant education and experience, as well as significant time necessary to perform a detailed exam which includes all relevant measurements. In contrast, a brief look at the heart by ultrasound, lasting several seconds or minutes, using eye-balling method, without any measurements, could be enough to get relatively informative answers on several main questions related to heart's performance (5). Those questions are as follows: What is the left ventricle size and contractility? Is there a significant pericardial effusion? Are there signs of the right ventricular overload? What is the inferior vena cava diameter and how is it changing by respirations?

Heart is mainly surrounded by lungs which contain air and, thus, prevent further ultrasound penetration. When using the ultrasound, the Heart should be approached from the regions where it is not covered by lungs. Typical cross-sections of the heart can be obtained from the epigastria and from the left parasternal region, as well as from the apex. From the epigastria and from the parasternal area, the heart is approached by side according to the main heart axis. Longitudinal (long axis) and transversal (short axis) cross-sections are of most interest. When approaching the heart from the apex, the middle ultrasound beam is positioned almost as if it was the heart axis, thus showing basis of the heart distally on the screen. Narrow probes which can fit into the intercostal place with a wide and deep field of view and of rather low frequencies (2.5-5 mHz) are the best suitable way for the examination of the heart. Linear convex probes (so called abdominal probes) can serve such a purpose, but sometimes apical view could be difficult to obtain.

By estimating the left ventricular size and contractility in a patient with shock, the

attending physician can assume contribution of the pump failure in the etiology of shock. If the left ventricle is dilated and has small wall excursions, it suggests a cardiogenic shock. A small, hyperdynamic heart is usually found in shock due to hypovolemia, when the left ventricular cavity can be almost empty at the end of systole. Absolute and relative hypovolemia can lead to the similar findings in a patient with septic shock, but sometimes due to the septic cardiomyopathy, impairment in the contractility of the heart can influence the findings. In the case of pericardial effusion, an anechoic layer around the heart can be seen. The collapse of the heart chambers during diastole, particularly the right atrium and the right ventricle, is a sign of tamponade.

The right ventricular dilatation with inter-ventricular septum shifted toward the left ventricle is suggestive of the right ventricular overload. By estimating the thickness of the right ventricular wall, it is possible to differentiate the acute from the chronic right ventricular overload, but this requires higher than basic level of expertise and also some experience. The acute right ventricular overload is often caused by pulmonary embolism. Dilated vena cava inferior, signs of venous thrombosis, and exclusion of the excess of the extravascular lung water support this diagnosis (6).

In the case of the cardiac arrest, focused cardiac ultrasound can be useful in guiding cardiopulmonary resuscitation (7, 8). In such a situation, it is important not to interrupt chest compressions, but instead take a brief look at the heart only when it is time to check the rhythm and pulse according to the recommended advanced life support algorithm. The ultrasound probe should be ready in the epigastria so that the most of the moment without chest compression can be used to observe and record heart action.

Exact measurements of the cardiac output are possible by echocardiography. By measuring the diameter of the left ventricular outflow tract and calculating the average speed of blood passing through during systole, the stroke volume can be calculated, which, if multiplied by heart rate, corresponds to the cardiac output, if the heart rate is regular. For such analysis, the ultrasound devices should have pulsed wave Doppler and software for calculating the velocity time integral. Dimensions of the inferior vena cava

(IVC) diameter can provide information about the circulatory volume. It was shown that inferior vena cava diameter and its reduction of the diameter during inspiration in spontaneously breathing patients correlates well with central venous pressure (CVP), particularly if the central venous pressure is low (9-13). Narrow IVC with marked reduction of the anteroposterior diameter during inspiration implicates hypovolemia. A dilated vena cava with little or no oscillation in the diameter regarding the breathing is suggestive of hypervolemia or other causes of elevated central venous pressure, such as the right ventricular failure, pulmonary embolism, cardiac tamponade etc.

A lot of studies were done with the aim to predict CVP in different patients by using different techniques and sites of the measurements. Most commonly, as recommended by American Society of Echocardiography, the measurements are performed just proximally of the inflow of the three hepatic veins. The CVP estimated by such measurements is presented in the table (Table 1). Despite the fact that measurements are simple and seem very exact, errors are possible due to the oval cross-section of the vena cava, and its nonparallel walls. Measurements are often performed in the M mode, where movements caused by the diaphragm motion, and the oblique instead of the right angle of the ultrasound beam regarding the direction of the IVC, produce some errors. Other conditions such as depth of breathing and mechanical support of breathing should be taken into account. Physicians experienced in ultrasound can estimate the volume status just by simple visual impression of the inferior vena during several breathing cycles, without doing any measurements, and processing automatically other variables, such as the breathing pattern and the right heart function, which can influence the interpretation.

## LUNG ULTRASOUND

Because air/water border is a strong reflector of ultrasound due to the significantly different acoustic properties, lungs containing air are supposed to be inaccessible by ultrasound. The most important scientific contribution for the development of a concept of lung ultrasound belongs to French intensivist Daniel Lichtenstein (14-20). The first international recommenda-

tions on lung ultrasound were published in 2012 (21). One of the most important applications of lung ultrasound is the ability of the ultrasound to detect excessive extravascular lung water. The appearance of diffuse B lines is suggestive of the lung edema, hydrostatic or is due to capillary hyperpermeability. With some certainty, it is possible to distinguish one from the other directly through the use of ultrasound, but clinical data should never be skipped (22). Inhomogeneous bilateral distribution of B lines with spared areas, pleural line abnormalities, sub pleural consolidations, and regions with fixed parietal end visceral pleura with no lung sliding are common findings in patients with ARDS. The amount of extravascular lung water can be roughly categorized as interstitial syndrome where some extravascular water is supposed to be in the lung interstitium, interstitial/alveolar where some fluid is also in alveoli's, and as lung consolidation, where alveoli are completely full with fluid (23). "Dry" lungs do not generate B lines on its surface; instead, only A pattern is seen on the screen of the ultrasound device while performing lung ultrasound. B lines are hyperechoic "sun-beam-like" artifacts which move by lung sliding, and originate from the pleural line and reach the end of a screen (14,15,16). In the case of lung consolidation, ultrasound can penetrate into the lungs so that the lung structure can be seen on the screen with hyperechoic air in bronchi (19, 24-27).

By distinguishing "dry" from "wet" lungs, a better understanding of a patient's pathophysiological process can be achieved, and this can have significant implication on the interventions with the aim to improve impaired hemodynamics.

Volume restitution is the mainstay of the treatment of majority of shock states. But it is not only a question about whether it is expected that fluid administration improves hemodynamic, but also in which amount the fluid could be beneficial. The patients with impaired left ventricular function are particularly at risk of over-treatment. FALLS protocol is a simple concept applicable to patients with initially "dry" lungs (28). By frequent monitoring of lungs, volume restitution can be limited by the first appearance of lung B lines. At that moment, first signs of higher amount of water in lung interstitium suggest that the left ventricle preload is on the optimal point of Frank-Starling curve, and that further volume administration can

worsen lung function due to lung congestion. At that point, lung function is still not impaired and maximal left ventricular output can be expected.

The potential of lung ultrasound in diagnosing pneumothorax, potentially reversible cause of shock and arrest, can be extremely helpful in some cases (29-31).

## OTHER

In traumatized patients, finding the free fluid in the body cavities assumes there exists internal bleeding with already devel-

oped or threatening hemorrhagic shock. FAST protocol, based on the pioneer work by Kristensen, was one of the first applications of the ultrasound in emergency medicine. (32-39). In some circumstances, there is no time for further investigations, but aggressive fluid and blood derivatives administration should be continued on the way directly into the operating room.

Detection of the aortic aneurysm in a patient presenting with pain and shock, even when ultrasound signs of dissection or rupture are not obvious, should direct further investigations to prove or exclude them first.

Vascular access is of utmost importance while managing a patient in a circulatory failure. Fluid administration is particularly important in the hypovolemic shock, when the empty veins can be a challenge to access. The ultrasound assisted or guided vascular access facilitates central venous access (40). Interventional procedures, performed by the ultrasound aid, such as pericardiocentesis, pneumothorax drainage, abscesses drainage etc. are essential in the treatment of the underlying causes of shock without which favorable outcome is unlikely (41-44).

Table 1. Estimation of central venous pressure by measuring inferior vena cava diameter and collapsibility index in spontaneously breathing subjects, as recommended by American Society of Echocardiography.

IVC diameter (cm)	Respiratory change	CVP (cmH <sub>2</sub> O)
< 1.5	Total collapse	0-5
1.5 - 2.5	> 50% collapse	6-10
1.5 - 2.5	< 50% collapse	11-15
> 2.5	< 50% collapse	16-20
> 2.5	No change	> 20

CVP; central venous pressure, IVC; inferior vena cava

## CONCLUSION

By using the ultrasound, clinicians have the opportunity "to see" the main components of the circulatory system, the heart function, and the filling status of the patient, so that the important information

can be immediately integrated into the process of clinical thinking at the bedside of a hemodynamically unstable patient. By understanding the mechanism of shock, optimal treatment can be instituted. Also, reversible causes of shock and arrest can be detected. By monitoring lungs by ul-

trasound, the amount of volume reinstitution to the optimal point of Frank-Starling curve can be titrated in some cases in a simple, noninvasive and accurate way.

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